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Life cycle analysis of organic tomato production and supply in Sweden

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ABSTRACT

Improving sustainability of organic tomato value chains requires increase of production and reduction of losses and related environmental burden. This paper presents the study conducted on organic tomato produced and consumed in Sweden. Using life cycle analysis (LCA) method with SimaPro8.2 LCA software, the cumulative energy demand (CED) and global warming potential (GWP_{100}) were investigated within the system boundary of cradle-to-consumer gate. The system was modeled as fresh tomato value chain (FTVC) and dried tomato value chain (DTVC). The functional unit (FU) was 1 ton of fresh product at farm that will be delivered to customer either as fresh or dried tomato. Sensitivity analysis was done considering changes in drying energy consumption. The results indicated that calculated CED values were 44.58 GJ and 49.40 GJ per functional unit for FTVC and DTVC respectively. Similarly, GWP_{100} values were 547.13 kg CO_2 eq and 467.44 kg CO_2 eq for FTVC and DTVC respectively. Agricultural production has been identified as hot-spot stage in both FTVC and DTVC cases. Next to agricultural stage, post-harvest and transport stages have been hot-spot stages for energy demand and climate impact respectively. Energy for greenhouse heating and irrigation as well as material for greenhouse construction contributed to the high impact of tomato cultivation stage. Packaging and drying activities at post-harvest stage and fuel consumption at transport stage contributed more to environmental burden. The drying process increased the energy demand while it reduced climate change impact. The drying process also could reduce the product losses and increase the product shelf life. This could improve the sustainability of locally produced organic tomato value chains, especially if integrated with renewable energy sources.

1. Introduction

1.1. Background

Agricultural sector contributes significantly to environmental impacts, like global warming, eutrophication, acidification, land degradation, and water depletion (Notarnicola et al., 2015; Longo et al., 2017; Tamburini et al., 2015). The sector is the contributor of most of environmental impacts. For instance, about 40% of global land area is covered by agriculture; 70% of global water withdrawal is for agriculture; and 30% of greenhouse gas emissions come from agricultural activities (Foley, 2010). In European Union, agriculture occupies about 45% of land use and more than 30% of total water use (Tamburini et al., 2015). The environmental impact of food production and consumption constitutes about 20–30% of individual's total environmental impact (Stoessel et al., 2012; Notarnicola et al., 2017).

Gases emitted from agricultural sector consist primarily of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) and primarily emitted from food production (Johansson, 2015). The sector is the major contributor to climate change impact through energy use, livestock, fertilizer production, pesticide production, machineries, land use change and soil degradation. Due to environmental issues mentioned above, there is increased demand of information on environmental impact of food by consumers and food supply chain actors. This necessitates the expansion of knowledge base on impact of agriculture sector and development of innovative and sustainable food production methods. In this regard, organic food production is getting more attention.

European Commission has prepared regulation (EC) 834/2007 so that organic agricultural production and food processing should follow defined general principles and rules (European Commission, 2007). In organic agricultural production, there is decrease of environmental load due to avoided use of chemical fertilizers. However, there is additional use of fuel to activities such as weed management even though its impact is less compared to benefit

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due to avoided fertilizers (Tamburini et al., 2015). Applying organic farming system could be used to build soil fertility and avoid industrial fertilizers and pesticides (Raghu, 2014).

Organic food is perceived to be tastier and healthier and its demand is increasing (Dias et al., 2017; Bosona and Gebresenbet, 2018). On the other hand, there is shortage of vegetables such as tomatoes. Therefore, greenhouse based production is used in many countries to meet the demand for tomatoes. In cold climate areas such as Sweden, the greenhouse based production is energy intensive which could lead to unsustainable way of production (Mariani et al., 2016; Dias et al., 2017). In addition, there are reasons that indicate organically produced food may not necessarily have less environmental burden. For instance, low production yield and long transportation of organic food due to its increasing demand could increase its environmental burden (Theurl et al., 2014). Therefore, it is important to conduct more LCA studies and create better knowledge base for improvement of sustainable tomato production or for comparison of alternative supply of vegetables such as importing to Sweden.

1.2. Goal and scope

The goal of this study was to assess the environmental burdens of organic tomato produced and distributed in Sweden. It was intended to investigate the effect of tomato drying process on environmental impact of organic tomato value chain. Accordingly it aimed to address the following research questions: What is the environmental impact of locally produced Organic tomatoes in Sweden? How drying process influences the environmental impacts of organic tomato? What are the environmentally hot-spot stages of organic tomato value chain?

First, the LCA of fresh tomato value chain (FTVC) was conducted. Then the drying process was introduced and LCA of dried tomato value chain (DTVC) was conducted. The assessment is based on functional unit of 1 ton of fresh tomato harvestable at farm gates. In FTVC the 1 ton harvested fresh tomato is to be sorted and transported to wholesaler where it will be further distributed to retail. In DTVC the harvested 1 ton fresh tomato will be transported to wholesaler facility where it will be dried and distributed to retail as dried tomato. All losses along both FTVC and DTVC have been taken into consideration.

1.3. Literature review

The study on environmental impact of tomato production is limited and results vary depending on varies reasons such as boundary conditions, production method and region of agricultural production. Especially, there is lack of studies on impact of organic tomato value chain. Table 1 presents some literature based values of energy demand and greenhouse gas emission from tomato value chains studied under different system boundary conditions and different countries.

Vegetable value chains are associated with losses which contribute to food loss and increased environmental burden. Tomato drying process increases shelf life and reduces product loss. In this study, the influence of tomato drying on environmental burden has been investigated.

The quality characterstics for dried tomato has been prepared by commercial quality standards of the United Nations Economic Commission for Europe (UNECE) known as Standard DDP-19: dried tomatoes (UNECE, 2007). According to this standard, fresh tomatoes can be dehydrated in different sizes varying from whole tomatoes drying up to ultra-finely diced tomatoes. The moisture content of dried tomato is considered to be in wet base (UNECE, 2011) and it depends on its required texture (see Table 2).

Food processing such as drying process requires considerable amounts of energy. At the same time, energy efficiency is important to improve the use of globally increasing demand of energy resource and reduce related environmental impacts (Amón and Simmons, 2017). Therefore more studies are required to identify opportunities to improve the energy demand in food processing.

In general, the need of increased knowledge on environmental impact of agricultural products is increasing. Due to the significant environmental impact of food production and consumption, many government agencies and companies have started to encourage the quantification of these environmental impacts. The quantification results enable to label food products and communicate with consumers, to make information-based decision regarding food production and supply chain management (Stoessel et al., 2012). However, there is lack of studies on organic tomato value chain and related environmental impact in Sweden (see Section 1.1). In this regard, the results of this LCA study will have contribution.

2. Materials and methods

2.1. Study area and yield

This study was based on organic tomato production in Southern Sweden. Although it has shorter growing season, tomato is produced mainly in Southern region of Sweden (Röös and Karlsson, 2013). Under conventional production in Sweden, Karlsson (2011) reported tomato yield of 11 kg/m2 for unheated greenhouse condition and 57 kg/m2 for heated greenhouse condition. Similarly,

Table 2
Moisture content of dried tomatoes with different textures (UNECE, 2007).

Moisture designation	Minimum – maximum perecentage	Texure
High moisture	25–50	Soft and pliable
Regular moisture	18–25	Firm but pliable
Reduced moisture	12–18	Very firm
Low moisture	06–12	Hard and brittle

Table 1
Examples of estimated impacts of tomato supply chain under different system boundary conditions.

System boundary	Functional unit	Production country	CED	GWP [kg CO_2 eq]	Reference
Conventional tomato production and supply to wholesaler	1 kg of tomato	Sweden		0.5–2.75	Karlsson (2011).
Conventional tomato production in greenhouse (including raw material input and material disposal)	1 ton of fresh tomato at farm gate	Spain	4 GJ	250	Torrellas et al. (2012)
Conventional tomato production in greenhouse	1 kg of fresh tomato	Sweden	66 MJ		Carlsson-Kanyama et al. (2003)
Conventional tomato production	1 kg of fresh tomato	Southern Europe	5.4 MJ		Carlsson-Kanyama et al. (2003)
Tomato production	1 kg fresh tomato at farm gate	Denmark		3.5	Mogensen et al., 2009
Tomato production and harvesting	1 ton tomato at farm gate	Iran	1.934 GJ	65.8	Zarei et al. (2017)

Hilmkvist (2015) reported tomato yield of 42.4 kg/m2 in Sweden under heated condition. From the primary data of this study, the yield varied from 7.8 kg/m2 to 35 kg/m2 for heated greenhouse conditions. Considering the literature based values for Sweden heated greenhouse condition and the primary data, 35 kg/m2 yield has been used in this LCA study. This value is less than literature based values due to the fact that organic production method gives fewer yields than conventional system per production area. In Sweden, harvest season is mainly from April to November under the heated greenhouse conditions.

2.2. System description

The study considered the case of tomato production and consumption within Sweden. It was assumed that both fresh and dried produces were cultivated in the same area, southern Sweden. The system boundary of this LCA study is cradle-to-consumer gate i.e. it starts from agricultural production and ends at consumers' gate (Fig. 1). The agricultural phase included cultivation (traction) and tomato seedling, organic fertilizer supply and application, irrigation, and harvesting and material and energy inputs from LCA perspective (see Section 2.3). Transporting harvested produce to processing facility at wholesaler, from the wholesaler to retail, and from retail to consumer has been included. Tomato washing, sorting, drying and packaging activities are included in post-harvest stage activities. Tomato storing and cooling activities were considered at retail facility.

In both cases, the product life cycle consists of three major stages: agricultural production (farming), post-harvest process, and transport activities. However, the system studied ends at consumer gate and excludes consumption level and waste management. It also excludes the production and supply of machines such as drying machine.

2.2.1. Agricultural production

A greenhouse based tomato production system was considered and the energy and material input for different activities are described in Section 2.5. Energy for traction, irrigation, seedling production, and heating greenhouse are included from different sources. Major materials for greenhouse construction include concrete, steel, aluminum, glass, and nylon (See Section 2.3). Renewable energy sources (woodchips) are used for heating greenhouses (Röös and Karlsson, 2013). Resources could be used efficiently when crops produced in greenhouse. However, greenhouse construction material and energy demand increase the environmental impacts (Torrellas et al., 2012). Animal manure was considered as organic fertilizer. The manure could be considered as waste product from livestock production. In relation to manure application, the emission to air such as nitrous oxide (N_2O) and ammonia (NH_3) was estimated based on data retrieved from SimaPro database of LCAFood DK data base for organic tomato production in Denmark (LCAfood, 2007). Fig. 2 depicts typical example of tomato production in greenhouse from Southern Sweden.

2.2.2. Post-harvest processes

In FTVC, activities covered at Post-harvest stage include sorting and washing, and packaging while there is drying process in DTVC case. The water and energy consumption are provided in Section 2.3. Tap water has been considered for washing purpose and it was assumed that tomato washing consumes about 400 kg of water per FU (Stoessel et al., 2012).

The drying process was assumed to be carried out at wholesaler facility at 80 km away from farm location. The energy consumption of drying machine was taken to be 1 kWh per each kg of water removed. The drying machine considered in this case is Biosec-Master Plus BMP72. It is made in Italy and can be used for varieties of products. Its empty weight is 250 kg and is totally stainless (Agritechstore, 2018).

Although tomatoes can be dried in different sizes, the Triple Diced tomatoes (Random pieces which are approximately 6–12 mm in length) have been considered (UNECE, 2007). In this study, the moisture content of 12% was assumed for dried product which is minimum moisture content to get very firm dried tomato (see Table 2). Accordingly, fresh tomatoes will be dried from a moisture content of about 93%–12% (See Table 3). Table 3 presents the percentage of dry matter and moisture content for both FTVC and DTVC together with quantity available to be dried per FU. Considering 10% product loss before drying process at wholesale, 900 kg fresh tomato will be dried and expected dried product is about 72 kg per FU (Table 3).

For packaging, Polyethylene terephthalate (PET) plastic boxes have been considered in both FTVC and DTVC cases. However, cardboard containers have been excluded. The product should be protected and needs appropriate packaging material which is free of all foreign matter (UNECE, 2007). Fig. 3 depicts packaging Examples for fresh and dried tomatoes.

2.2.3. Product transport

The transport segments considered include farm-to-wholesaler facility, wholesaler-to-retail, and retail-to-consumer gate. In the first two transport segments, only single trip has been considered.

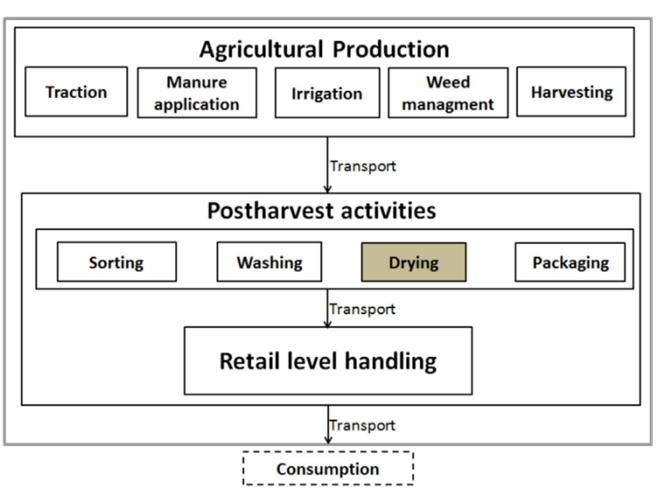

Fig. 1. System boundary and process flow chart.

Fig. 2. Tomato cultivation in heated greenhouse in Sweden (Ålmås Gård farm, 2016a).

Table 3
Parameters and quantity of fresh and dried tomatoes in reference to FU.

Value chain	FTVC			DTVC		
Parameter	Total weight	Dry matter	Moisture	total	dry matter	moisture
	TW	DM	MC	TW	DM	MC
Amount [%]	100	7	93	100	88	12
Amount [t]	0.90	0.063	0.837	0.072	0.063	0.009

a b

Fig. 3. Tomato packaging. Source: (a) Packing fresh cherry tomatoes from farm in Sweden (Ålmås Gård farm, 2016b); (b) Dried tomato from a retail in Sweden (Matsmart retail, 2018).

From farm to wholesaler, 80 km has been assumed based on information from data survey. The distance between wholesaler and retail was taken as 50 km while from retail to consumer 5 km was considered.

For farm-to-wholesaler and wholesaler-to-retail, EURO6 refrigerated freight lorry of capacity 7.5–16 ton was used with its background data provided in database of Ecoinvent 3. For retail-to-consumer a passenger car was considered assuming 10 kg of fresh tomato per purchase which was considered to be about 10% of total food stuff purchased. For dried tomato case, 10% of amount purchased fresh tomato has been assumed.

2.2.4. Tomato losses along value chain

Losses start at harvesting stage. Considering post-harvest losses, losses occur during sorting and packaging, handling at warehouse (wholesaler), and at retail. As noted from primary data survey, total loss during harvesting, sorting and packaging could vary from 1% to 20% and 5% has been assumed for this analysis. Losses during transport to wholesaler and handling at warehouse could vary from 1% to 5% (Röös and Karlsson, 2013; Högberg, 2010). For DTVC case, additional loss of 5% has been considered during preparation for drying i.e. 0.90 t of fresh tomato would be available for drying at wholesaler per FU and about 0.072 t dried tomato could be delivered to retail per FU (see Table 4).

There is allocation problem, as the portion of harvested produce has been wasted as indicated above. In this case, the environmental burden due to production of wasted amount is also assigned to 1 ton functional unit (FU) considered. In DTVC case, it was also assumed that all useable (remaining from waste) fresh tomato would be dried. There is also allocation problem when purchase of different food stuff considered. It was assumed that tomato purchase will constitute only portion of total purchase and environmental burden will be assigned accordingly using mass allocation.

2.3. Life cycle inventory (LCI)

Data has been collected for both FTVC and DTVC from both primary and literature based data sources. Ecoinvent database version 3 and peer-reviewed articles have been used (see Table 5). However, all input data have been recalculated per FU of the current study. For some processes, there is limitation to get data. In such case, estimation was based on market information. For instance, for tomato washing related data, a machine with capacity of 1 t/h and 1.5 kW power was considered based on information from marketing website on (Alibaba, 2017a). Similarly, data for tomato slicing machine with a capacity of 0.5 t/h and 0.75 kW power consumption was considered based on information from marketing website (Alibaba, 2017b). The open access LCAFood database which includes organic tomato and covers most food items produced in Danish/North European countries has been used to retrieve some data for this study (LCAfood, 2007).

2.4. Life cycle impact assessment

Environmental burden can be assessed using input-related indicators such as energy demand, land use, and water use and output-related indicators such as climate change impact or carbon footprint, damage to water body, acidification of land and water, and human toxicity (Curran, 2015; Notarnicola et al., 2015). In this study primary energy consumption and climate change impact have been investigated.

The life cycle impact assessment (LCIA) was done by modelling both TFVC and DTVC cases in SimaPro LCA software, version 8.2. Attributional LCA approach was applied. In this analysis, cumulative energy demand (CED) method was used for assessment of energy demand, and Europe ReCiPe (H) midpoint method was used to assess global warming potential (GWP_{100}) (PRé Consultants, 2016; ReCiPe, 2008). Using the CED method the primary energy

Table 4
Tomato losses along value chain expressed as percentage of initial production.

Supply chain stage	Initial production at farm stage	During sorting and packaging	During handling at warehouse (wholesaler)	Retail	Comment
Losses [%]	–	5	1	5	Röös and Karlsson, 2013; Högberg (2010)
Cumulative loss [%]	–	5	6	11	
Useable product [t]	1	0.95	0.94	0.89	Useable product per FU for FTVC case
Dried tomato [t]	1	0.95	0.90t (fresh); 0.072t (dried)	0.072t	For DTVC case

Table 5
Input data at different stages of Tomato product cycle.

Description	Unit	Quantity per FU
Farming stage (Agricultural production)		
Irrigation water (Sweden)	L	12000[a]
Energy for Traction	MJ	54[b]
Electricity for (irrigation and lighting)	MJ	1657.14[c]
Wood chips for greenhouse heating	MJ	40000[c]
Natural gas	MJ	1429[c]
Heat for seedlings production (from natural gas)	kWh	230[b]
Electricity for seedling production	kWh	79[b]
Steel (life time 40 years)	kg	7.85[c,d]
Aluminum	kg	1.79[c,d]
Concrete	kg	35.73[c,d]
Nylon ropes (to tie tomato plants)	kg	0.97[b]
Glass	kg	9.28[c,d]
Post-harvest process		
Water for washing tomatoes	L	380[e]
Energy for sorting and washing	kWh	1.43[f]
Energy for tomato slicing	kWh	1.43[g]
Plastic boxes (PET) for packaging fresh tomato	kg	26.6[h]
Electricity for drying	kWh	828[a]
Packaging plastic box (PET) for dried tomato.	kg	2.16[j]
Electricity for cooling at retail for fresh tomato	MJ	53.58[d]
Electricity cooling at retail for dried tomato	MJ	4.104[d]
Transport		
Transport segment farm-to-wholesal facility	km	80[a]
Transport segment wholesal-to-retail	km	50[a]
Transport retail-to-consumer gate	km	5[a]

[a] Calculated based on primary data survey of SusOrganic project.
[b] Based on LCAfood data retrieved from SimaPro software.
[c] Based on Röös and Karlsson (2013).
[d] Based on Karlsson (2011).
[e] Based on Stoessel et al. (2012).
[f] Estimated based on marketing information on (Alibaba, 2017a).
[g] Estimated based on marketing information on (Alibaba, 2017b).
[h] Based Theurl et al. (2014).

consumption has been evaluated (Frischknecht et al., 2015) at different life cycle stages of FTVC and DTVC such as agricultural production, post-harvest handling and processing as well as transport activities at different transport segments. The sensitivity analysis was done to investigate how the improvement in energy consumption could affect the CED and GWP_{100} values in comparison to FTVC case. The sensitivity analysis was performed by changing (reducing and increasing) the drying energy consumption by 30% (see section 3.4).

3. Results

Table 6 presents the contribution of major life cycle stages to estimated total CED and GWP values. For FTVC case, CED value is 44.58 GJ while GWP_{100} is 547.13 kg CO_2 eq. Similarly, for DTVC case, CED value is 49.40 GJ while GWP_{100} is found to be 467.44 kg CO_2 eq. Fig. 4 and Fig. 5 indicate that agricultural production is hot-spot stage in both FTVC and DTVC cases. Next to agricultural stage, post-harvest is hot-spot stage regarding CED (see Fig. 4) while it is transport when climate impact is considered (see Fig. 5). Energy for greenhouse heating, irrigation and material for greenhouse construction contributed to the high impact of tomato cultivation stage. Packaging and drying activities at post-harvest stage and fuel consumption at transport stage contribute more to environmental burden.

3.1. LCIA at agricultural production stage

Activities at agricultural production stage are similar for both FTVC and DFVC cases. The agricultural production stage includes the greenhouse management and heating. The total CED at this stage is found to be 41 GJ which represents about 92% of total value in FTVC, and 83% in DTVC case (see Table 6 and Fig. 4). The energy demand is mainly for irrigation activity and green house heating. The greenhouse uses mainly renewable energy source from biomass (wood chips). The renewable biomass contributes to 79% of the total CED estimated for agricultural production stage. Regarding GWP_{100}, in both FTVC and DTVC cases, it was calculated to be 366.39 kg CO_2 eq which constitutes about 67% of total value for FTVC case, and 78% for case of DTVC (see Table 6 and Fig. 5).

3.2. LCIA at post-harvest stage

Major activities contributing to CED and GWP are washing, packaging, and retail cooling. The total CED calculated for post-harvest stage of FTVC case has been 2.17 GJ which represents 5% of total CED. The main contributor is found to be packaging. This indicates that if cardboard has been included, the impact of packaging increases more and improving packaging contributes to reduction of environmental impacts. When DTVC is considered, the energy demand at post-harvest stage increased from 2.17 GJ to 7.61 GJ due to drying process. The drying process contributes about 98% of estimated CED at post-harvest stage. On the other hand, when compared with FTVC case, the energy demand for packaging and storage/cooling activities decreased by 92% due to the volume reduction of dried tomato to be handled. The energy source for post-harvest activities is electric energy from Sweden national electricity grid where renewable hydropower energy and non-renewable nuclear energy sources contribute the most shares.

The calculated greenhouse gas emission values at post-harvest stage are 88.12 kg CO_2 eq and 48.64 kg CO_2 eq for FTVC and DTVC cases respectively. These values represent 16% and 11% of total GWP100 values in FTVC and DTVC respectively. In FTVC case, packaging is the major contributor to GHG emissions at post-harvest stage while in DTVC drying and packaging contributes the major part. The drying constitutes 85% of emission at post-harvest stage.

3.3. LCIA at transport stage

At transport stage, fossil fuel contributes the most to CED. The total transport energy demand depends on the transport distance and truck used. In this study, the 80 km farm-to-wholesaler

Table 6
Life cycle stages contribution to different impact categories per FU.

Value chain	Impact category	Unit	Agricultural production	Post-harvest[a]	Transport[b]	Total
FTVC	CED	GJ	41	2.17	1.42	44.58
	GWP_{100}	kg CO_2 eq[c]	366.39	88.12	92.63	547.13
DTVC	CED	GJ	41	7.60	0.80	49.40
	GWP_{100}	kg CO_2 eq	366.39	48.64	52.41	467.44

[a] Post-harvest stage includes drying process.
[b] Transport stage includes transport from farm to processing facility and from facility to retail.
[c] kg CO_2 equivalent.

Fig. 4. Contribution of life cycle stages to CED.

Fig. 5. Contribution of life cycle stages to climate change impact.

transport segment contributes more to CED and GHG emissions. Since the drying was introduced at wholesaler facility, the CED and GHG emission values from farm-to-wholesaler transport segment are the same for both FTVC and DTVC cases (see Figs. 6 and 7).

When compared with FTVC per FU, the energy demand for transport stage of DTVC case reduced from 1.42 GJ to 0.80 GJ while the GWP_{100} value reduced from 92.63 kg CO_2 eq to 52.41 kg CO_2 eq (reduction of 44% for both CED and GWP) due to reduced volume of product after drying process.

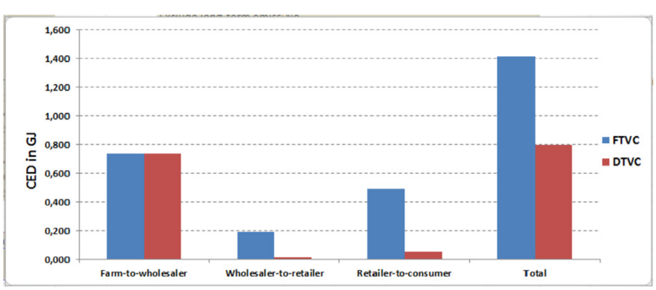

Fig. 6. CED estimated for transport activities per FU.

Fig. 7. Climate change impact of transport activities per FU.

3.4. Sensitivity analysis

Due to the drying process the total CED of DTVC increased when compared with that of FTVC case. The analysis result indicates that, improving the drying energy consumption is important to reduce environmental burden. The 30% reduction or increase in drying energy consumption could result in 4.5% reduction or increase in total CED value of DTVC respectively. Similarly, it could reduce or increase the total GWP of DTVC by 2.7%. However, if agricultural stage, which is not affected by drying process, is excluded, the decrease and increase will be by 26.42% and 12.24% for CED and GWP respectively (see Table 7).

4. Discussion

The result in this study confirms that energy consumption at

Table 7
Influence of reduction or increase in energy demand for tomato drying on total CED and GWP.

Impact category	CED GJ	Change [%]	kg CO_2 eq	GWP Change [%]
Considering all life cycle stages				
30% reduction	47.18	(−)4.5	455.07	(−)2.7
Basic scenario	49.40	0	467.44	0
30% increase	51.62	(+)4.5	479.81	(+)2.7
Excluding agricultural production stage				
30% reduction	6.18	(−)26.42	88.68	(−)12.24
Basic scenario	8.40	0	101.05	0
30% increase	10.62	(+)26.42	113.42	(+)12.24

agricultural production stage contributes more to environmental burden. Although direct comparison of produces from different agricultural areas and different production method (conventional and organic methods) is difficult, Table 8 presents a comparison between the LCA results of the current study and some other LCA studies on tomato in Sweden and other countries in Europe. Although the production methods and system boundaries could vary, the comparison enables to have better understanding on impacts of tomato production under different conditions (greenhouse based production and open-field based production) and regions with different climate conditions.

Considering studies based on greenhouse based production and 1 ton fresh tomato at farm, the calculated primary energy demand values are 5.4 GJ, 4 GJ, and 66 GJ in southern Europe, Spain, and Sweden respectively (see Table 8). The result from the current LCA study is found to be 41 GJ when only agricultural stage is considered and 44.58 GJ when post-harvest and transport stages are included (see Table 6). Under similar conditions of production explained above (see Table 8), calculated greenhouse emission values are 3500 kg CO_2 eq in Denmark and 250 kg CO_2 eq in Spain. Considering cradle-to-wholesaler gate (Karlsson, 2011), greenhouse gas emission was calculated to be between 500 and 2750 kg CO_2 eq in Sweden (see Table 8). The calculated result from current study is found to be 547.13 kg CO_2 eq which is within the range indicated above.

Even though it reduces need of tomato import and promotes local production in Sweden, the results from the current LCA study and literature indicate that agricultural production stage of tomato is energy intensive. Due to the cold climate of Sweden, outdoor production of tomatoes is very limited (FAO, 2001). On the other hand, the production in greenhouses demands more energy to heat up the greenhouses (Högberg, 2010). This environmental impact increases when the vegetable is exposed to losses. In Europe the cumulative loss (and waste) of fruits and vegetables along entire supply chain from agricultural to consumption stage is estimated to be about 45% of initial production where the agricultural and consumption stages have significant contribution of 20% and 11% respectively (Gustavsson et al., 2011).

Theurl et al. (2014) investigated greenhouse gas hotspots along tomato supply chains and pointed out that carbon footprints vary for different production systems such as prevalence and absence of greenhouse heating energy demands. Due to more energy needed for greenhouse heating, environmental burden of tomato is higher than field-grown tomatoes (Mogensen et al., 2009). Similarly, the current study indicates that agricultural production stage contributes more to environmental burden.

Therefore, increasing the use of renewable energy and improving the efficiency of resource use at farm stage could improve the sustainability of supply of locally produced organic tomato. Post-harvest stage contributes more to CED than transport stage while transport contributes more to GWP_{100} than post-harvest stage. This is due to more energy demand for post-harvest activities and more emissions from fossil fuel used for transport. Less transport demand requires less fossil fuel and thus produces less greenhouse gas emission (Theurl et al., 2014).

Reduction in volume of produce due to drying process reduces the environmental impact by reducing transport demand, packaging material and packaging process. Borghi et al. (2014) studied tomato production in Italy and discussed that agricultural phase and packaging process of tomato life-cycle have high impact potential. Their findings reflect the findings in the current study.

In general, the environmental burden increases as food distribution area increases. Röös and Karlsson (2013) discussed that even though, the emissions from vegetables production and consumption represents a minor portion of total emissions from food consumption, eating seasonal food such as carrots and tomatoes in Sweden can reduce carbon footprints by about 60% when compared to consuming those produced in heated greenhouse or transported from long-distance. The current LCA study was based on limited distribution area as described in Section 2.2.3.

When only transport stage is considered, the drying process reduced both CED and climate change impact by 43% when compared with transport stage of FTVC case. In this case, the system was modeled with assumption that the drying is to be carried out at wholesaler location which is about 80 km away from farm. The transport segment farm-to-wholesaler delivery with 80 km contributes more to CED and GHG emissions in both FTVC and DTVC cases. In DTVC case, it should be noted also that it is fresh tomato to be transported over farm-to-wholesaler segment while dried tomato to be transported over remaining transport segments (see Figs. 6 and 7). This indicates that locating the processing facility nearby the farm saves more resources.

The drying process is important to improve tomato preserving methods. Reducing food loss, improving food quality, shelf life, and food production and supply methods promote regional food production efforts. This in turn supports the rural development polices. Understanding the influence of the drying process on energy consumption and greenhouse gas emissions from organic tomato supply helps to craft more improvement strategies in vegetable supply chain. In general, the drying process increased energy demand by 11% and reduced the greenhouse gas emission by 15% when all life cycle states considered. However, when agricultural production stage is excluded, the CED value increased by 134% and GWP_{100} value reduced by 44% respectively. In addition to reducing climate change impact, the drying process reduces the product losses and increases the shelf life of locally produced organic

Table 8
Comparison of quantified environmental impact values of the current study with some existing studies in Sweden and other countries in Europe. In all cases the primary energy consumption and greenhouse gas emission are considered.

Brief system description	Impact category	Quantity	Reference
Organic tomato production in Sweden; System boundary of cradle-to-consumer gate	Energy consumption per ton of fresh product at farm Greenhouse gas emission per ton of fresh product at farm	44.58 GJ 547.13 kg CO_2 eq	Current study
Conventional tomato production in **Sweden**; System boundary of cradle-to-wholesaler	Greenhouse gas emission per ton of fresh product	500-2750 kg CO_2 eq	Karlsson (2011).
Conventional tomato production in **Sweden** using greenhouse	Energy consumption per ton of fresh product	66 GJ	Carlsson-Kanyama et al. (2003)
Conventional tomato production in **Southern Europe**	Energy consumption per ton of fresh product	5.4 GJ	
Conventional tomato production in **Spain** using greenhouse	Energy consumption per ton of fresh product Greenhouse gas emission per ton of fresh product	4 GJ 250 kg CO_2 eq	Torrellas et al. (2012)
Tomato production in **Denmark**; Production (fam) stage analysis	Greenhouse gas emission per ton of fresh product	3500	Mogensen et al., 2009

tomatoes.

From sensitivity analysis, under the system boundary conditions of this study, a 30% reduction of energy for drying process could reduce CED by 4.5% and greenhouse gas emission by 2.7%. This could be further improved if renewable energy sources are used. In this regard, the findings of this study could be useful database that benefit the potential users to understand the environmentally hotspot areas in organic tomato value chains.

In general, although limited LCA studies on tomato are available (see Tables 1 and 8), more studies are required to increase knowledge base in Europe in general and Sweden in particular. In this regard, the current study has some important contributions. It presents scientific data of LCA and more understanding on environmental impact of organic tomato production and supply in Sweden. To the knowledge of the authors, this is the first LCA study on organic tomato cultivation and supply in Sweden. It is also the first LCA study that investigated how drying process could influence the environmental burden of organic tomato value chain. It was learnt that even though drying process consumes additional energy, it can be traded off by reduction of product volume and packaging material which in turn reduces transport fuel and post-harvest product loss, especially in case of transporting to long distance. This indicates that DTVC has less energy demand and greenhouse gas emission than FTVC especially when distance to market increases. This contributes to the LCA study data base on organic foods in general and organic tomatoes in Sweden in particular. The findings could be used by farmers, food processors, decision makers, organic food consumers, as well as researchers.

5. Conclusion

The goal of this study was to assess the environmental burdens of organic tomato produced in greenhouse and locally distributed in Southern Sweden while investigating the effect of tomato drying process on environmental impact. For this purpose fresh tomato value chain (FTVC) and dried tomato value chain (DTVC) were considered. Attributional life cycle assessment (LCA) method with cradle-to-consumer gate approach was used where agricultural production, post-harvest handling, and transport activities were considered. A functional unit of 1 ton fresh tomato at farm gate was used in both FTVC and DTVC cases. Tomato drying was assumed to be carried out at wholesaler facility located at 80 km from farm. Three transport segments were included: farm-to-wholesaler, wholesaler-to-retail, and retail to consumer gate.

This life cycle impact assessment (LCIA) was carried out using SimaPro LCA software, version 8.2. Two impact categories: cumulative energy demand (CED) and global warming potential (GWP_{100}) were investigated. The calculated CED value is 44.58 GJ for FTVC and 49.40 GJ for DTVC. Similarly, the calculated GWP_{100} value is 547.13 kg CO_2 eq for FTVC and 467.44 kg CO_2 eq for DTVC. Agricultural production stage is environmentally hot-spot in terms both energy consumption and emission in both FTVC and DTVC cases. In both FTVC and DTVC, next to agricultural stage, post-harvest is hot-spot stage for CED while it is transport stage for case of climate impact.

The drying process increased energy demand by 11% and reduced the greenhouse gas emission by 15% when all life cycle states considered. In addition to reducing climate change impact, the drying process reduces the product losses, packaging materials, and transport volume while it increases the product shelf life. The environmental sustainability could be relatively increased for DTVC if distribution distance is increased as a result of further reduction in transport fuel when compared to case of FTVC. The findings of this study are important references for organic food producers, policy makers, researchers, and consumers.

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